**ERAD-0060    CLIMATOLOGICAL PROCESSING AND PRODUCT DEVELOPMENT**
**FOR THE TRMM GROUND VALIDATION PROGRAM**

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# Abstract

A comprehensive Ground Validation (GV) Program has been implemented to validate TRMM satellite observations. The primary goal of TRMM GV is to provide basic validation of satellite-derived precipitation measurements over monthly climatologies for the following primary sites: Melbourne, Florida (FL); Houston, Texas (TX); Darwin, Australia; and Kwajalein Atoll, Republic of Marshall Islands (RMI). As part of the TRMM GV effort, research analysts at NASA Goddard Space Flight Center (GSFC) generate standardized rainfall products using quality-controlled ground-based radar data from the four primary GV sites.

An overview of TRMM GV climatological processing and product generation, including description of the data flow between primary GV sites, NASA GSFC, and the TRMM Science Data and Information System (TSDIS) is presented. The radar data quality control (QC) algorithm, which features eight adjustable height and reflectivity parameters, together with the methodology used to create standardized monthly, gauge-adjusted rainfall products for each primary site is summarized. Presented are statistics from recently reprocessed official GV radar rainfall products which include derived monthly gauge bulk-adjusted Z-R relationships, area-averaged rain rates, radar-to-gauge accumulation ratios, gauge acceptance/rejection ratios, and radar data availability. Official climatological GV products, statistics, and descriptions can be found at the Internet address http://trmm.gsfc.nasa.gov/TRMMGV/GVproducts.html.

## 1. Introduction

Quantitative knowledge of tropical rainfall is a primary goal of TRMM (Simpson et al. 1996; Kummerow et al. 1998). A comprehensive Ground Validation (GV) program has been developed to evaluate TRMM observations. Key components of GV are the analysis and QC of meteorological ground-based radar data from four primary sites: Melbourne, FL (WSR-88D); Houston, TX (WSR-88D); Darwin, Australia (C band); and Kwajalein Atoll, RMI (WSR-93D-S band). As part of the TRMM GV effort, the Joint Center for Earth Systems Technology at the University of Maryland – Baltimore County, the Center for Earth Observing and Space Research at George Mason University, and NASA Goddard Space Flight Center have been tasked with developing and implementing an operational/climatological system to QC TRMM GV data and create official radar and rainfall products from the four primary sites. Provided is a brief overview of the TRMM GV climatological data processing and product development environment, together with preliminary results.

## 2. TRMM GV Data Processing and Level 1 Products

Figure 1 depicts the overall flow of TRMM GV data. Radar data tapes from the GV primary sites are sent to GSFC, where the data are extracted and QC'ed to create official TRMM GV radar and rainfall products. Radar data are collected on 8-mm tapes and sent directly to GSFC. Data from the Houston, Melbourne, and Kwajalein sites are collected on a year-round basis, while the Darwin radar operates only during the rainy season (November through April).

As discussed in Kulie et al. (1999), radar data are processed into two official TRMM GV level 1 products which are maintained in hierarchical data format (HDF) over hourly time intervals and conform to official archival standards of the Goddard Distributed Active Archive Center (GDAAC). The first product, TRMM Standard Product Number (TSPN) 1B-51 contains uncorrected radar reflectivity, Doppler velocity, and differential reflectivity (Kwajalein and Darwin) fields out to a maximum range of 230 km. All radar scans collected over hourly time intervals are packaged into 1B-51 files, or granules. The second level 1 product, TSPN 1C-51, contains a QC'ed radar reflectivity field, plus a corrective mask that is applied to the uncorrected reflectivity field. The uncorrected reflectivity field can be obtained by simply removing the mask from the corrected reflectivity field. Data are QC'ed using the Ground Validation System (GVS) package developed by the TRMM Office.

## 3. QC Algorithm

The purpose of the 1C-51 QC algorithm is to remove non-precipitating radar echoes that may negatively impact the quality of higher-level (2 and 3) TRMM GV rainfall products. The QC is needed to remove spurious echo, such as clutter associated with insects, birds, chaff, wildfires, physical structures, and anomalous propagation (AP). The QC algorithm employed to generate 1C-51 products is a modified version of the algorithm developed by Rosenfeld et al. (1995). The algorithm uses eight adjustable parameters, three echo height (H) thresholds and five radar reflectivity (Z) thresholds to remove non-precipitating radar echoes. Radar echoes are masked within ~5x5 km$^2$ windows (in polar coordinates) by the algorithm if any of the following criteria are satisfied:

1.  $\{H_{top} < H3$ or $Z_{max}(3$ km$) \leq Z1\}$ and $\{Z_{max}(H1) < Z3\}$;

2.  $H_{top} < H2$;

3.  $Z_{max}(1.5$ km$) < Z0$;

4.  $\{Z > Z_{noise}$ and $Z \leq Z2\}$ in lowest tilt;

where $H_{top}$ is the echo top height (defined by the $Z_{noise}$ threshold) and $Z_{max}$ represents a maximum reflectivity value at a specified height. If any of the conditions are met, radar echoes are masked up to a level of H3+1 km. Height checks are made only when the echo top height is less than the top of the volume scan being investigated.

Each TRMM GV site presents different combinations and patterns of false radar echoes and real precipitation. Thus, the QC algorithm has varying degrees of success that are site dependent. Differences in algorithm performance are also strongly affected by topography (e.g. orography, coastlines, etc.) and climatological profiles of moisture and temperature at the lowest levels of the atmosphere. Therefore, unique default parameters are used for each GV site. These defaults are frequently tuned when spurious echo remains after initial QC processing. The QC algorithm has demonstrated an ability to remove a wide variety of false echo scenarios because of parameter flexibility. Specifically, it effectively removes biological targets (e.g. birds), shallow, non-embedded AP and clutter specks, and light second-trip and clear-air echoes.

In general, the algorithm can remove many moderate to strong false echoes located within 100 km of the radar, but it often has difficulty removing these echoes at longer ranges, especially when precipitation is present. Spurious echo embedded in real precipitation echo results in algorithm failure. Robinson et al. (1999) discusses the spurious echo trends observed at the Melbourne GV site, and how performance of the QC algorithm is linked with seasonal variability of false echo types.

4.  **Climatological Product Development**

The ultimate objective of the TRMM GV program is to produce high quality rainfall products for validation of TRMM satellite observations. To this end, research analysts at NASA GSFC produce instantaneous rain rate, as well as pentad (5-day), and monthly rainfall accumulation products for each of the four primary TRMM GV sites. These products are standardized in that the same methodology for deriving gauge-adjusted rainfall products is used for each site. Several generations of products have evolved as described in Robinson et al. (2000).

Official GV monthly rainfall products are developed in discrete modular steps with distinct intermediate products. These developmental steps include: (1) extracting QC'ed radar data over the locations of rain gauges (Figure 2); (2) merging gauge and radar data in time and space; (3) automated QC of radar and gauge merged data (Amitai, 2000); and (4) deriving bulk-adjusted reflectivity (Z) and rainfall (R) relationships from the QC'ed merged data over monthly time scales.

Accumulations of rain rates from the radar and accepted gauges (average 7-minute gauge rain rate centered at volume-scan time) are calculated and used to derive independent bulk-adjustments to Z-R coefficients for convective and stratiform rain types. Initially, a single Z-R relationship, $Z = 300R^{1.4}$, is used for radar-derived rainfall over the gauges for both rain types. Bulk-adjusted dual classification coefficients are derived from the initial Z-R relationship using the following equations:

$$A(\text{stratiform}) = 300(R_{strat}/G_{strat})^{1.4} \tag{1}$$

$$A(\text{convective}) = 300(R_{conv}/G_{conv})^{1.4} \tag{2}$$

$R_{strat}$ ($R_{conv}$) is the stratiform (convective) rain rate accumulation from the radar over all the gauge locations combined, and $G_{strat}$ ($G_{conv}$) is the stratiform (convective) rain rate accumulation from the gauges. Note that the exponent of 1.4 is used for both rain types. This bulk-adjustment method of forcing the radar-estimated accumulations to match those from the gauges is justified in order to account for known and unknown adjustments in the radar calibration. If the total accumulated rainfall from all accepted gauges is < 250 mm, R/G statistics from previous months are combined to generate a more robust Z-R table. The derived bulk-adjusted convective and stratiform Z-R relationships are then applied to 1C-51 data to obtain instantaneous surface rainfall rates within 15-150 km of the radar (TSPN 2A-53). The instantaneous rain rates are then integrated to produce pentad (TSPN 3A-53) and monthly (TSPN 3A-54) rainfall products.

## 5. Gauge and Rainfall Product Statistics and Preliminary Results

Table 1 shows a sample of preliminary gauge and rainfall product statistics for each primary GV site. Complete data can be found on the Internet web site. It is difficult to discern trends in R/G ratios and coefficients from month to month due to the fact that known and unknown calibration adjustments are incorporated into these ratios. Early results show that R/G ratios are near unity for both stratiform and convective rain types during summer months dominated by diurnal sea-breeze convection (Melbourne 7-98, Houston 8-98). This means that very little adjustment to the initial Z-R relation is required. However, lower R/G ratios are obtained during months dominated by stratiform rainfall from tropical systems, such as Tropical Cyclone (TC) Mitch affecting rainfall statistics from Melbourne in November 1998 and TC Frances dominating the rainfall statistics over Houston in September 1998. Lower R/G ratios indicate significant radar rainfall underestimation compared to the gauges, resulting in lower coefficients (and higher rain rates) in the bulk-adjusted Z-R relation. The radar underestimation from months dominated by mainly stratiform events agrees with results found by Klazura et al. (1999), and Amitai (2000). A radar calibration change of +4.0 dBZ occurred at the Houston site in mid-February '98, which has contributed to the R/G ratio change from Jan to Feb 98. The precipitation regime at Kwajalein is purely tropical in nature, and is not influenced by land. For this reason, Kwajalein is arguably the most important GV site. For Kwajalein, R/G ratios are quite low resulting in large bulk-adjustments to the initial Z-R, and indicating possible inadequacy of the initial Z-R and/or radar calibration uncertainties. August through December 1998 show much lower R/G statistics than previous months mainly due to calibration uncertainties. There is very little data available from the Darwin, Australia site to draw meaningful conclusions. January 1998 was the only month when radar data was available for more than 90% of the time.

## 6. Summary

A comprehensive GV program has been developed to evaluate observations from TRMM. Provided is an overview of this operational/climatological production environment. Key components of GV are the analysis and QC of meteorological radar data from four primary sites: Melbourne, FL; Houston, TX; Darwin, Australia; and Kwajalein Atoll, RMI. The described QC algorithm employs eight adjustable height and reflectivity parameters. Research analysts at NASA GSFC analyze and QC radar data and produce standardized official products, which are transferred to the Goddard DAAC and made available to the science community. The TRMM GV Climatological Product Development web site, located at http://trmm.gsfc.nasa.gov/TRMMGV/GVproducts.html, provides many resources including product descriptions and inventories, Z-R table generation statistics, quick-look images of

monthly rainfall accumulations, and official standardized products with supporting statistics.  For more information

on GVS, see the TRMM Office web page at the Internet address http://trmm.gsfc.nasa.gov/trmm_office/index.html.

## 7.   Acknowledgments

The authors are grateful to Dr. Ramesh Kakar (NASA Headquarters), Dr. Robert Adler (TRMM Project

Scientist), Dr. Chris Kummerow (former TRMM Project Scientist), and Mr. Richard Lawrence (TRMM Office,

Head), for funding and support of this effort.  John Merritt, Bart Kelley, Galen Wilkerson, Mike Kolander, and Thuy

Nguyen, are acknowledged for software development and support.  We also appreciate the efforts of the Houston

and Melbourne National Weather Service Offices, Aeromet, Inc., and the Australian Bureau of Meteorology

Research Center.

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Table 1:  Sample gauge, Z-R, and rainfall statistics from primary Ground Validation sites.  The "GAUGES" column represents the number of good gauges after automated QC, and the total number of gauges before QC.  Also shown are dual-classified radar to gauge (R/G) ratios and bulk-adjusted (A) coefficients.  Area-averaged rainfall (mm/day), and amount (in percent) of monthly radar data available (in parentheses) for each month are shown in the final column.  Area-averaged rainfall statistics are adjusted to the percentage of radar data available.  The asterisk (*) denotes months where rainfall accumulation in good gauges is less than 250 mm, and R/G statistics from previous months are combined to generate more robust Z-R statistics.

| SITE MM-YY | GAUGES GOOD/ TOTAL | R/G TOTAL | A TOTAL | R/G STRAT | A STRAT | R/G CONV | A CONV | AREA AVG RAINFALL (MM/DAY) |
|---|---|---|---|---|---|---|---|---|
| **HSTN** 01-98 | 71/80 | 0.64 | 162 | 0.42 | 89 | 0.70 | 181 | 4.53 (95%) |
| 02-98 | 66/80 | 1.08 | 333 | 1.27 | 421 | 0.94 | 274 | 4.28(91%) |
| 08-98 | 57/80 | 0.88 | 253 | 0.96 | 283 | 0.86 | 242 | 4.96(77%) |
| 09-98 | 61/80 | 0.43 | 93 | 0.42 | 89 | 0.45 | 97 | 10.63(84%) |
| | | | | | | | | |
| **MELB** 01-98 | 36/61 | 0.79 | 214 | 0.77 | 207 | 0.80 | 219 | 3.52(90%) |
| 02-98 | 59/64 | 0.93 | 272 | 0.98 | 293 | 0.90 | 260 | 7.07(96%) |
| 07-98 | 42/83 | 0.98 | 294 | 1.22 | 394 | 0.95 | 277 | 4.42(96%) |
| 11-98 | 41/74 | 0.66 | 166 | 0.58 | 138 | 0.92 | 266 | 3.49(97%) |
| | | | | | | | | |
| **KWAJ** 12-97 | 3/9 | 0.44 | 96 | 0.47 | 103 | 0.43 | 92 | 6.26(98%) |
| 01-98* | 0/9 | 0.44 | 96 | 0.47 | 103 | 0.43 | 92 | 0.42(94%) |
| 08-98 | 4/10 | 0.17 | 25 | 0.16 | 24 | 0.18 | 27 | 7.64(73%) |
| 09-98 | 2/9 | 0.15 | 20 | 0.15 | 22 | 0.14 | 20 | 8.16(87%) |
| 10-98 | 2/9 | 0.24 | 40 | 0.30 | 56 | 0.22 | 37 | 24.40(21%) |
| 11-98 | 3/9 | 0.30 | 55 | 0.38 | 77 | 0.27 | 49 | 7.40(94%) |
| 12-98* | 2/8 | 0.28 | 50 | 0.30 | 57 | 0.27 | 48 | 6.03(83%) |
| | | | | | | | | |
| **DARW** 12-1997 | 13/20 | 0.69 | 178 | 0.64 | 160 | 0.71 | 187 | 8.96(66%) |
| 01-1998 | 12/15 | 0.67 | 170 | 0.66 | 169 | 0.67 | 170 | 10.75(91%) |
| 12-1998 | 19/22 | 0.50 | 115 | 0.50 | 113 | 0.51 | 116 | 7.29(50%) |

**Figure Captions**

**Figure 1**: Simplified flow diagram of TRMM Ground Validation data processing and climatological product development.  Radar data are first processed into official Level 1 products where an iterative quality control algorithm is employed.  Higher-level rainfall products are then created, before transferring the products to the TRMM Science Data and Information System (TSDIS).

**Figure 2**: The spatial window (3x3 matrix) of radar data extracted over the locations of each rain gauge.  The gauge is physically located under the center reflectivity pixel.  Each grid cell is 2x2 $km^2$, and the overall window size is 6x6 $km^2$.  Radar data are extracted at altitudes of 1.5 km and 3.0 km.  The symbols Cn and Zn represent the convective/stratiform classification and reflectivity, respectively, of the $n^{th}$ pixel.
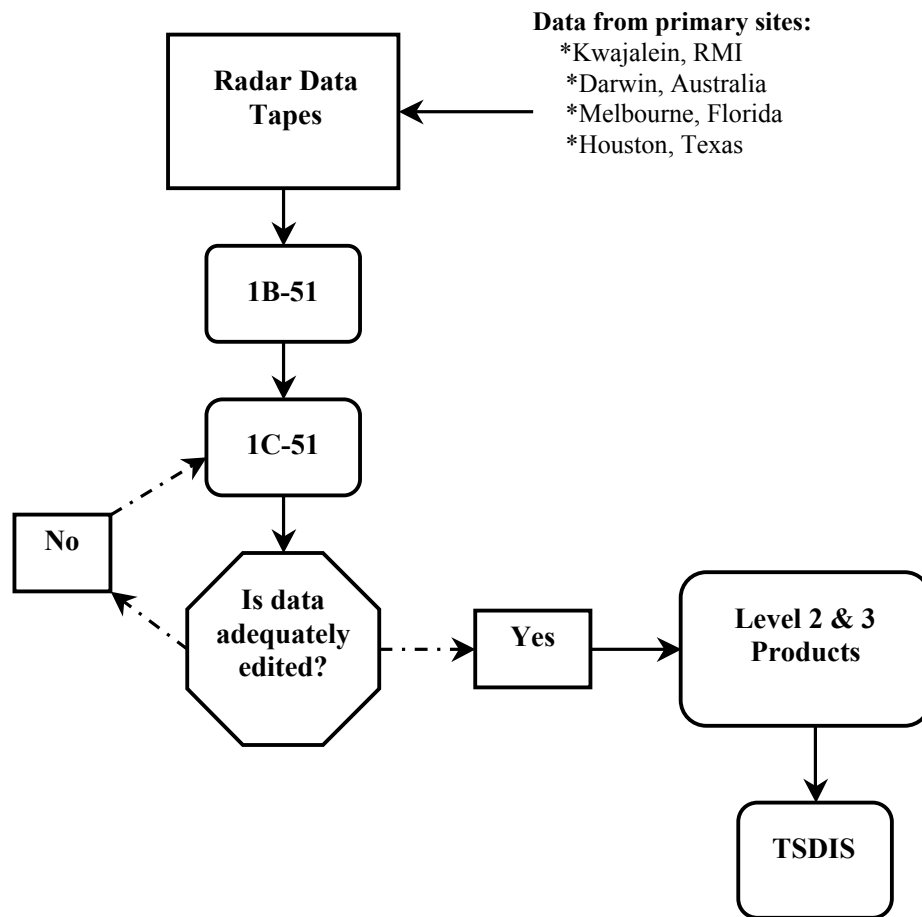
```
┌─────────────────┐                    Data from primary sites:
│  Radar Data     │◄──────────────       *Kwajalein, RMI
│  Tapes          │                       *Darwin, Australia
└─────────────────┘                       *Melbourne, Florida
        │                                 *Houston, Texas
        ▼
   ┌─────────┐
   │ 1B-51   │
   └─────────┘
        │
        ▼
   ┌─────────┐
┌──│ 1C-51   │
│  └─────────┘
│       │
│       ▼
┌────┐  ╱────────╲           ┌──────┐     ┌─────────────┐
│ No │◄─│ Is data │          │ Yes  │────►│ Level 2 & 3 │
└────┘  │adequately│········►│      │     │ Products    │
        │ edited?  │         └──────┘     └─────────────┘
        ╲─────────╱                              │
                                                 ▼
                                          ┌─────────────┐
                                          │   TSDIS     │
                                          └─────────────┘
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Figure 1
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| | | |
|---|---|---|
| C7,Z7 | C8,Z8 | C9,Z9 |
| C4.Z4 | *gauge location<br>C5,Z5 | C6,Z6 |
| C1,Z1 | C2,Z2 | C3,Z3 |

Figure 2